NOMINATION
OF THE

MEADOWBANK RAILWAY BRIDGE PARRAMATTA RIVER 1886 - 1980

AS AN

HISTORIC ENGINEERING MARKER

Prepared for the
Engineering Heritage Committee
Sydney Division, I E Aust
by
Don Fraser and Ross Best
August 2000

CONTENTS

STATEMENT OF SIGNIFICANCE

1. The Meadowbank Railway Lattice Bridge, over the Parramatta River betwen Rhodes and Meadowbank, Sydney was completed in 1886. It is among the oldest of the surviving colonial railway bridges in New South Wales.

2. It was the eleventh in a set of twelve iron lattice bridges built between 1871 and 1887.

3. This set of bridges is the most significant group of railway bridges of colonial NSW.

4. The Meadowbank Bridge is the largest of the group.

5. The proponent of the use of the iron lattice bridges was Engineer-in-Chief John Whitton, acknowledged as the "father of NSW railways".

5. The bridge was a major item of infrastructure for the important 1889 railway link from Sydney to Newcastle.

6. It was part of the railway link that joined the northern New South Wales and Queensland railways to the railways of southern New South Wales, Victoria and South Australia which was used as a symbol of the emerging Federation of Australia.

7. The bridge has a commanding visual appearance on its tall pairs of cast iron cylinders.

8. Its heritage significance is enhanced by the juxtaposition of welded box girders which show the change in bridge technology in 100 years.

9. Although the bridge was decommissioned in 1980, its potential to serve under less demanding loads was recognised. A deck has been installed for use by pedestrians and cyclists, leaving the origia tracks in position.

EPPING
Marsfield
Macquarie University
West Killara
North Ryde
Eastwood
Denistone
Cemetery
East Ryde
West Ryde
RYDE
Meadowbank
Melrose Park
BRIDGE
Ryde Bridge
PARRAMATTA
Gladesville
Putney
Boronia Park
Hunters Hill
Homebush Bay
Rhodes
Brays Bay
Hospital
Mortlake Vehicular Ferry
Mortlake
Cabarita
Henley
Chiswick
Abbotsford
Hen and Chicken Bay
Concord
Canada Bay
Five Dock
Russell Lea
Rodd Point
Haberfield
STRATHFIELD
Homebush
Flemington
Burwood
Croydon
Ashfield
Summer Hill
Rookwood Cemetery
Rookwood
State Abattoirs
HIGHWAY
HUME HIGHWAY
WESTERN
FREEWAY
George Kendall Reserve
Gladesville Bridge
Fig Tree Bridge
Lane Cove River

Commemorative Plaque Nomination Form

Date December 2000

To:
Commemorative Plaque Sub-Committee
The Institution of Engineers, Australia
Engineering House
11 National Circuit
BARTON ACT 2600

From:
Engineering Heritage
Committee
Sydney Division

The following work is nominated for a :-

~~National Engineering Landmark~~

Historic Engineering Marker.

Name of work .... The 1886 Meadowbank Railway Bridge, Sydney

Location .... Over Parramatta River between Rhodes and Meadowbank

Owner .... State Rail Authoity

Owner's response .... Letter of agreement attached

Access to site .... Easy access as it is now a pedestrian/cycle way

Future care and maintenance of the work ..... Status to be monitored regularly by State Rail Authority

Name of sponsor ....

Donald C Cotter
....
Chairperson of nominating committee

ADDITIONAL SUPPORTING INFORMATION

Name of work .... The Meadowbank Railway Bridge

Year of construction or manufacture 1886

Period of operation .... 1886 - 1980

Physical condition .... Good condition

Engineering Heritage Significance :-

Technical, scientific value .... Largest lattice truss railway bridge in NSW

Historical value .... One of 12 lattice railway bridges, 1872-87

Social value .... Important railway link & partly symbol of Federation

Landscape or township value ...... Iron piers and lattice form have visual impact

Rarity .... One of 11 surviving railway lattice bridges

Representativeness .... As for Rarity, a good representative of group

Contribution to nation or region ..... See social value

Contribution to engineering .... A good example of British bridge technology

Persons associated with the work- John Whitton, Amos Bros. contractor

Integrity .... Largely intact, railway changes & cycle way work

Authenticity .... Mostly original construction

Comparable works (a) in Australia .... 10 others in NSW but lesser total lengths

(b) overseas ..... Many in Britain

Statement of Significance, its location in the documentation .... see Contents

Citation (70 - 80 words) - or refer to location in the documentation .... see Contents

Attachments to submission (if any) ...... Copy of a 1981 (returnable) video of the history and construction of railway lattice bridges in NSW.

Proposed location of plaque .... On stonework of northern abutment

STATE RAIL
Rail Estate Heritage
4th Floor, Transport House
11-31 York Street,
SYDNEY

Tel 9224 3026
Fax 9224 3544

6th November, 2000

TO WHOM IT MAY CONCERN

State Rail supports the initiative by the Institution of Engineers to affix a heritage plaque to the former Meadowbank railway bridge, built under the administration of John Whitton.

S. Sharp

Stuart Sharp
HERITAGE ADVISER

THE 1886 MEADOWBANK RAILWAY BRIDGE
PARRAMATTA RIVER, SYDNEY

DRAFT WORDS FOR THE PLAQUE

I E Aust
Crest

HISTORIC ENGINEERING MARKER

MEADOWBANK RAILWAY BRIDGE
(1886 - 1980)

This was the eleventh of John Whitton's 12 lattice railway bridges, 1871-87. It is the longest of the group, was only the second with double track and represented the pinnacle of British bridge technology. Fabricated in England, it was erected by local contractor Amos Bros at a cost of 69,000 pounds. It was part of the important 1889 railway link from Sydney to Newcastle which was used as a symbol of the emerging Federation of Australia. Out of service for 20 years it became a cycle and pedestrian path in April 2000. (92 words)

DEDICATED BY
THE INSTITUTION OF ENGINEERS, AUSTRALIA
2001

HISTORICAL OVERVIEW

In the early 1870s the burgeoning railways of New South Wales had reached 'gateways' to the hinterland at Goulburn (Main South) and Kelso (Main West) and was poised to tackle the heights of the New England ranges from Murrurundi (Main North).

The enormous costs caused the Colonial Government to hesitate about the extensions and sought to contain costs by advocating horse-drawn railways. Engineer-in-Chief, John Whitton, revised his estimates for the extensions as steam railways, using cheaper standards of construction (steeper grades, sharper curves, lighter rails and more timber bridges) and in 1873 the new Government authorised extentions to Wagga Wagga (Main South), Orange (Main West) and Tamworth (Main North).

However, the extensions would progressively encounter major rivers; the Murrumbidgee and Murray (Main South), the Macquarie at Bathurst (Main West), and on the Main North there was the Peel at Tamworth. Others would follow as the lines continued into the hinterland. Large-span bridges were essential to cross these rivers, already notorious for their large destructive floods.

Despite the 1869 timber laminated arch viaduct across the Hunter River at Singleton, Whitton chose to ignore the 1861 decree to use timber as much as possible, and instead chose the British iron lattice bridge, technically superior and offering the potential for a long service life with only routine maintenance. The Singleton timber viaduct was replaced by a steel truss in 1901 whereas Whitton's group of iron lattice bridges are extant over 100 years later.

The first of these iron lattice bridges had already been built in 1871 across the Hunter River at Aberdeen during construction of the Singleton to Murrurundi section of the Main North. So Whitton had a precedent. Eleven more were to follow ending at Cowra over the Lachlan River in 1887. Table I in the attached reference paper summarises all the information about these 12 bridges.

This was the most significant set of railway bridges built in colonial New South Wales and represented the pinnacle of use in the British bridge technology. The next most significant set of bridges was the American style trusses for the North Coast Railway (1911-22), designed

and fabricated in Sydney and erected by local contractors.

With Whitton's lattice bridges, only the erection was by local contractors. Although the basic designs were prepared in Sydney, the design check and the preparation of drawings were carried out by John Fowler in London, while fabrication was carried out by various British companies, except for the last bridge at Cowra which was supplied from Belgium, as shown in Table I in the reference paper.

Table I also shows that only two lattice bridge were for double track, at Albury for the wide gauge Victorian line and a standard gauge line, and at Meadowbank with two standard gauge lines for the Main North. So these two bridges were the widest ones. Technically, the Como bridge had two tracks but in a special configuration caled Gauntlet track. Table I also shows that there were only two 6-span lattice bridges, at Como and at Meadowbank, so the latter is the widest and longest, hence the largest, of the group.

The Meadowbank Bridge, its official railway name but often referred to by others as the Ryde Bridge which really the road bridge downstream, was load tested under the supervision of Whitton's deputy, Henry Deane, on the 10th September, 1886. His report of the 20th acknowledges John Whitton's presence. Five steam locomotives ranging in weight from 63 to 72 tons were run in various combinations and speeds back and forth across the bridge, during which deflections were recorded at the middle of each span. The maximum deflection was 1 inch, which in a span of 150 feet represents a very stiff structure. No wonder it was able to carry much heavier C38 passenger locomotives and D57 goods locomotives during the last 30 years of its service life!

Eventually, load and speed restrictions had to be applied and plans began immediately after World War II for its replacement. The initial design was for six double-track steel Pratt trusses and the piers were completed just as the 1952 recession took place. Work was suspended for 20 years during which the inadequacies of the old lattice bridge were imposing constraints on railway operations.

In 1972 the decision to replace was taken, but by then the new technology of lightweight steel welded box girders offered a much cheaper, more elegant solution than the large visually dominant trusses. The new box girder bridge, immediately upstream of the old, was completed in 1980 and has been named the John Whitton Bridge.

The original plan had been to use new concrete piers on the western side to carry double track steel trusses then, demolish the lattice bridge and build a new superstructure on the old iron piers. The new technology changed all that. The tops of the new concrete piers were widened to accommodate some form of 4-track superstructure (eventually the steel box girders) and the old bridge became redundant.

PHOTOGRAPHS OF 1886 BRIDGE

November, 2000

CONVERSION TO PEDESTRIAN/CYCLEWAY

Many attempts were made to pass off the lattice bridge to the

- Department of Main Roads (now Roads and Traffic Authority) for conversion to a road bypass to Ryde

- Water Board (now Sydney Water) because of its attached pipeline, and

- Australian Gas Light Company (AGL) ecause of its attached pipeline.

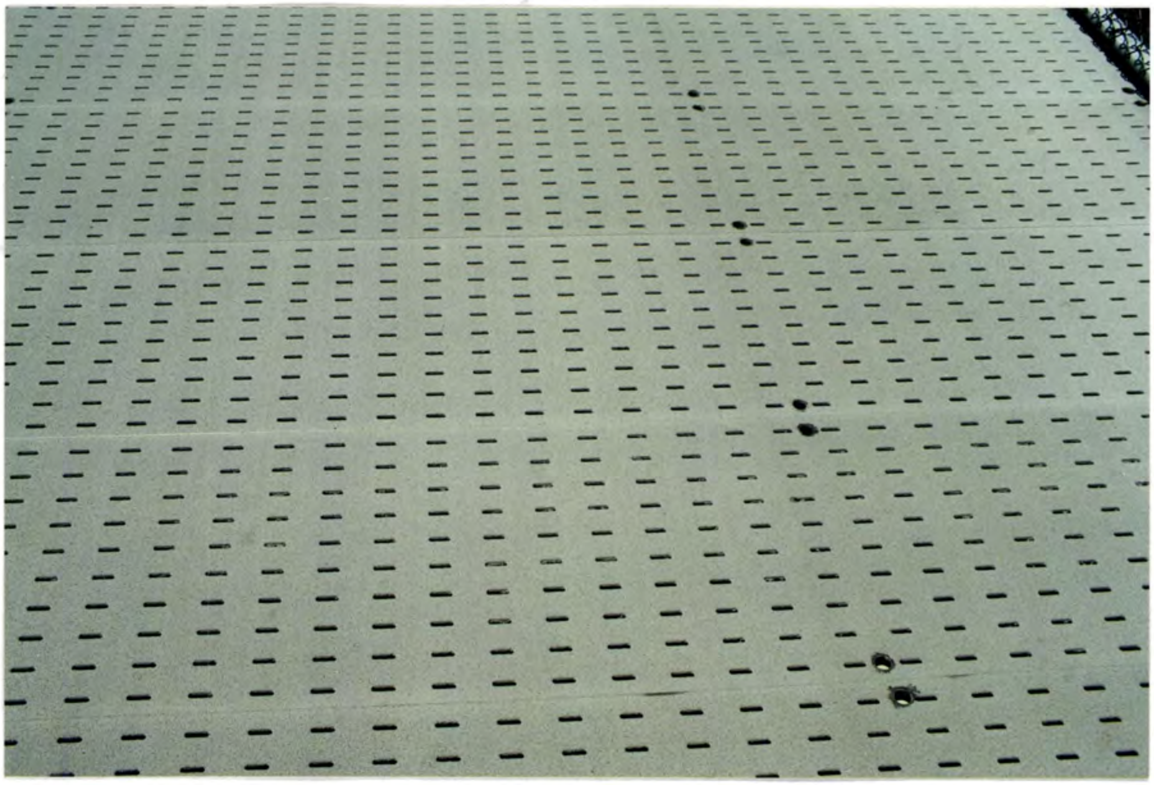
Also, plans were mooted to add a walkway to give access to the northern ferry wharf for southside residents.

All proved unsucessful, no one wanted it. In 1993 the owners, State Rail Authority (SRA), went so far as to draw up plans to demolish the the old bridge. However, there had been talk of using it as a cycleway and pedestrian path but no action ensued until preparations for the Olympics began. Suddenly, there was community discussion about saving the old bridge. One of the adjoining Municipal Councils obtained funds to investigate the conversion to a cycleway thereby linking the recently completed foreshore cycleways, south and north sides. This in turn lead to a meeting of Councils, the SRA and the RTA from which emerged a funding arrangement whereby all aprties shared equally the conversion cost. There was even an agreement in principal that the RTA would eventually assume responsibility for the old bridge.

This exercise has provided an important precedent that, while a use may not be found soon after an historical item is removed from service and there is the liklihood of early demolition, circumstances do change. New ideas and adaptive technology can produce viable options. In the case of the 1886Meadowbank Railway Bridge, the process took 20 years but the bridge was saved.

PHOTOGRAPHS OF THE PEDEDESTRIAN/CYCLEWAY

November, 2000



BASIC REFERENCE PAPER

Conference on The Protection
of the Engineering Heritage,
1982, Brisbane, 9-12 May

Railway Lattice Girder Bridges in New South Wales

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SUMMARY During the period 1880-1890 New South Wales experienced something of a railway mania. In the course of establishing a basic framework for the future railway network, some major river crossings were required; for example, across the Parramatta, Hunter and Murrumbidgee Rivers. In all, twelve crossings were involved and the same style of bridge was chosen for each, namely the iron lattice girder bridge. This paper traces the history of the lattice girder bridge, in particular the railway lattice girder bridges in New South Wales, and discusses details and methods of analysis. The paper also shows what is involved in historical research of works that are a significant part of our engineering heritage.

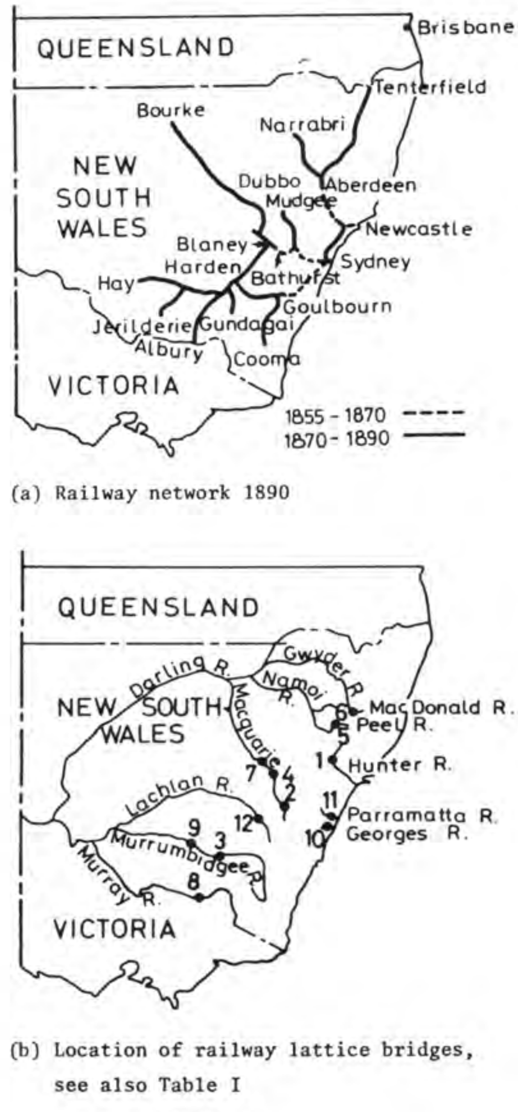
1 INTRODUCTION

Railway service in New South Wales began in 1855 with the opening of the line between Redfern and Granville some 20 km west of Sydney. During the next fifteen years portions of three main lines were built and by 1870 had reached Goulburn in the south, Bathurst in the west and Aberdeen in the north. The 500 km of railways then in use are shown with dashed lines in figure 1(a). Despite the achievement of building the famous Zig-Zag near Lithgow and erecting three major bridges, over the Nepean River at Menangle and at Penrith, and over the Hunter River at Singleton, rate of construction was only modest.

Then came a rapid acceleration. New South Wales experienced its own railway mania and in the next twenty years, 1870-1890, the length of operating lines increased seven-fold to 3500 km. The extent of this growth is shown by the full lines in figure 1(a). A basic framework north, south and west of Sydney had been completed, from which future extensions were to form the current network of 9000 km.

In the course of this twenty-year burst of activity, the railways had to cross four major coastal rivers (Parramatta, Georges, Hunter and Hawkesbury) and six inland rivers (Macquarie, Lachlan, Peel, MacDonald, Murrumbidgee and Murray). In all, fourteen crossings were involved. The Hawkesbury River Bridge, the biggest project, was an American truss design, not a lattice girder bridge, and so will not be dealt with here. A single-lattice girder bridge was built over the Parramatta River at Camellia in 1895 on the Carlingford Line but it was not one of the original twelve double-lattice bridges which are the subject of this paper. The location of these twelve bridges is shown in figure 1(b) and noted in Table I.

During the 1970's three of the original twelve lattice bridges were taken out of service following the construction of modern replacements, and could be destined for recycling as scrap-iron. The others are all past their economic lives and are also scheduled for replacement depending on availability of funds and other priorities. Eventually all will go and with them the tangible evidence of a pioneering era of iron bridge construction important to the colonial history of New South Wales.



(a) Railway network 1890

(b) Location of railway lattice bridges, see also Table I

Figure 1

TABLE I

LINE	No. *	TOWN	RIVER
Main North (Sydney to Tenterfield)	1	Aberdeen	Hunter
	5	Tamworth	Peel
	6	Woolbrook	MacDonald
	11	Ryde	Parramatta
Main South (Sydney to Albury)	3	Wagga Wagga	Murrumbidgee
	8	Albury	Murray
Main West (Sydney to Bourke)	2	Bathurst	Macquarie
	4	Wellington	Macquarie
	7	Dubbo	Macquarie
Narrandera to Jerilderie	9	Narrandera	Murrumbidgee
Illawarra (Sydney to Wollongong)	10	Como	Georges
Blayney to Harden	12	Cowra	Lachlan

* Chronological order of construction

2 THE LATTICE GIRDER BRIDGE

2.1 Origin

Figure 2 shows diagrams ot typical lattice girders, a form of construction also referred to as a trellis girder and as a double or multiple Warren girder.

Contrary to the commonly held view that Ithiel Town's timber lattice trusses (1820-1835) were the fore-runner of the metal lattice girders, the latter originated in Europe and Britain (Edwards, 1959). The multiple triangular iron girder/truss was an adaption of the Warren truss developed by Neuville and improved by Captain Warren (Matheson, 1877). Neuville, a Belgian engineer, designed and constructed one of these bridges in 1846 near Ghent. Another, built near Dublin around 1844 is reputedly the first in Britain (Hemans, 1844, Chrimes, 1980).

2.2 Scope of application

During the second half of the nineteenth century, the iron lattice girder became the dominant bridge type (both for road and rail) in Britain, in European countries and in their colonial empires. It was little used in America where the Whipple, Baltimore and Pratt trusses were the most popular types. Because of the widespread use of metal lattice girders, there is an abundance of technical information in contemporary journals and text books. The references in this paper are a sample.

Lattice girders, when properly designed and constructed, proved to be superior to all other non-American types (Baker 1873, Matheson 1877, Merriman and Jacoby 1898) over a wide range of spans, 18m (60 ft) to 90m (300 ft). There were some examples of spans up to 180m (600 ft).

The main advantages of the lattice girder were the saving in weight and its increased stiffness. The open web system enabled the sizes of the "web" members to be readily adjusted to suit changes in shear force, which gave significant savings in web material compared to a plate web girder, Figure 3. At the time, cost differentials made the costs of materials more important than labour costs. When combined with curtailment of the flange (chord, boom) materials , the lattice girder became a very efficient structure.

Increased overall stiffness and stability were achieved by using channel sections for compression web bars rivetted at their intersections with the flat-iron tension members.

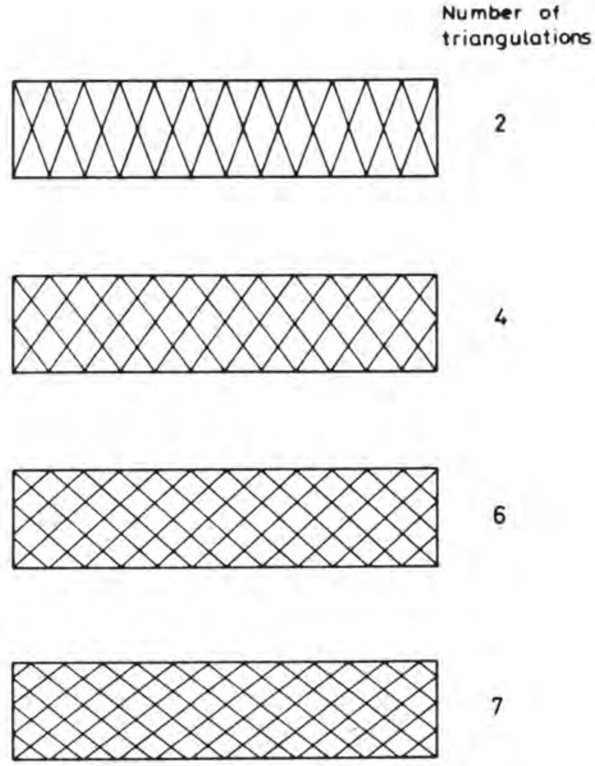


Figure 2 Typical lattice systems

A particularly useful series of papers by Cargill, dealing with iron lattice girders, was published in the Journal of the Franklin Institute, 1863.

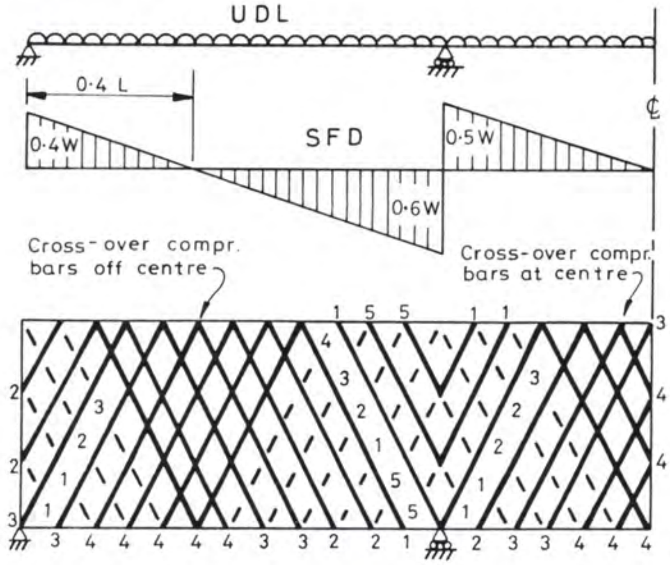
2.3 Some Standard Details

In addition to the basic classification of bridges (beam, arch, suspension), bridges are also classified according to the location of the deck relative to depth of the main girders/trusses, Figure 4. Lattice girders were used in all three situations. The pony bridge was so named because it was not deep enough to allow overhead cross-bracing of the top flanges (Johnson et al, 1894).

The most common form of lattice girder construction is the double-lattice web with multiple triangulations. A double-lattice web has two sets of parallel web bars, Figure 5(a), connected to trough or U-shaped chords. Nearly all lattice girder bridges in New South Wales are of this construction. The single-lattice web, Figure 5(b), is virtually an open-web plate web girder. An example, built in 1895, still exists carrying the railway over the Parramatta River at Camellia, Sydney. The author is not aware of any lattice webs in excess of two.

Multiple-triangulations refers to the number of independent Warren systems within the pattern of intersecting lattice bars. Figure 2 shows the most common numbers of triangulations. All the lattice road bridges in New South Wales have two triangulations hence the term double-Warren truss. Of the twelve railway lattice bridges reported in this paper, six have seven triangulations, four have four triangulations and two have six triangulations.

Without tracing the separate Warren trusses, the number of triangulations can be determined in two ways (Hart 1866), (1) count the number of diamonds and parts thereof in any vertical section and then multiply by two, or (2) take any lattice bar, count the number of intersections and then add one.



Tension		Compression	
Bars	Area mm^2	Bars	Area mm^2
1	8160	1	11 200
2	6400	2	8400
3	5600	3	7680
4	4800	4	6400
5	9760	5	14 000

——— Compression bars numbered outside the girder.

– – – – Tension bars numbered inside the girder.

Figure 3 Distribution of lattice bar sizes

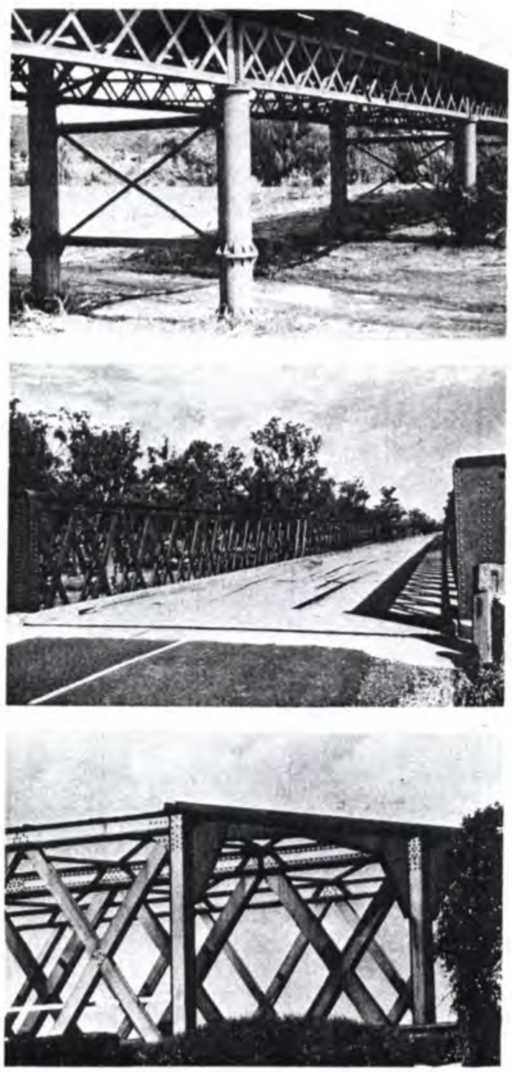


Figure 4 Lattice girder bridges. Deck, pony and Through bridges.

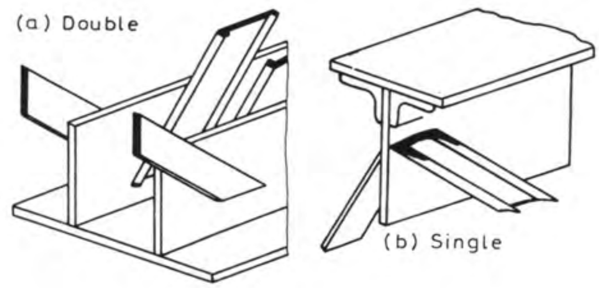


Figure 5 Lattice webs

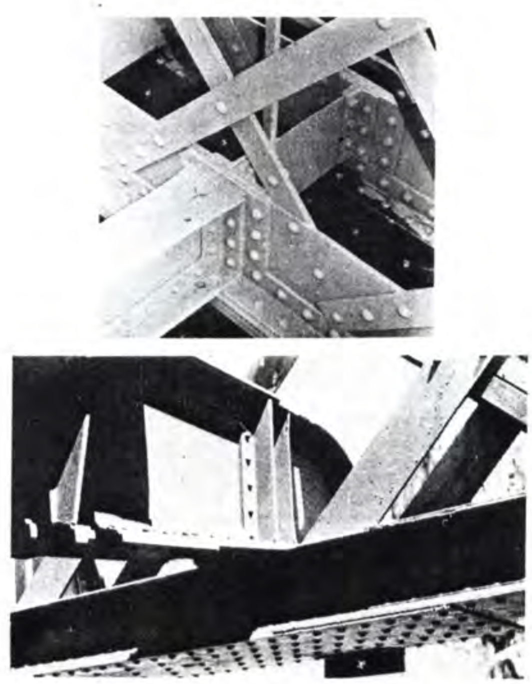
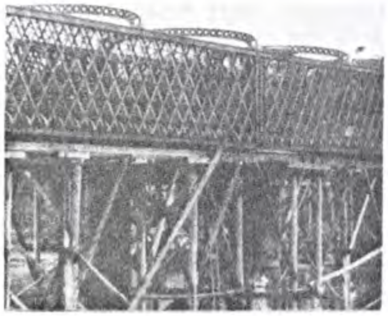


Figure 6 Connections of cross-girder to bottom chords, side and top connections.

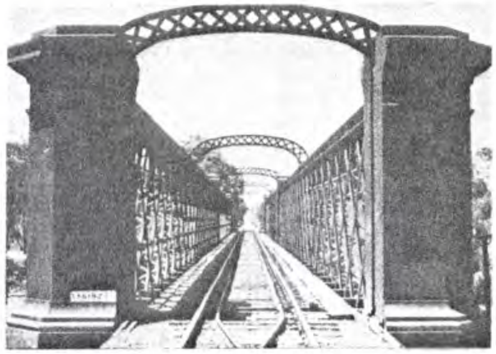
TABLE II

HISTORICAL INFORMATION FOR THE 12 RAILWAY LATTICE BRIDGES IN N.S.W.

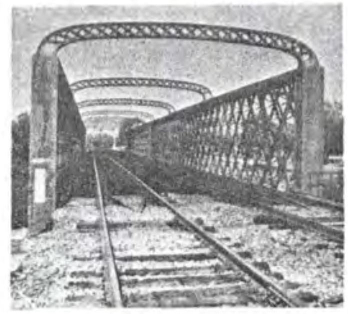
Period	Location River	No of tracks	No of spans 48.5m (159ft)	Contin-uous	No of triangu-lations	Principal Contractor	Supplier of Superstructure (weight in tons)	Erection Sub-contractor	Supplier of Cast Iron cylinders (wgt in tons)	Dates of load tests	Date put into service	Total cost £ cost/m
1870-71	ABERDEEN Hunter	1	3	Yes	7	Amos & Co	Park Gate Iron Co Rotherham, England (580)	Thomas Smithyman	Park Gate Iron Co	14 Feb 1871 19 Feb 1885	17 Apr 1871	£24,840 $341
1875-76	BATHURST Macquarie	1	3	Yes	7	J.S.Cummings. W.Mason (Jnr). Mason and Ellsington	Handyside & Co Derby, England (580)	Thomas Smithyman		8 Mar 1876 7 Jan 1885	4 Apr 1876	£31,130 $426
1879-81	WAGGA WAGGA Murrumbidgee	1	4	Yes	7	Amos & Co	P.W.McLellan Glasgow, Scotland (779)	J.S.Bennett	Stockton Forge Co Stockton-on-Tees (574)	16 Dec 1880 only	23 Jan 1881	£43,490 $446
1879-81	WELLINGTON Macquarie	1	3	Yes	7	W.Watkins	Handyside & Co Derby, England (580)	Thomas Smithyman	Stockton Forge Co (453)	25 Jan 1881 9 Jan 1885	1 Feb 1881	£45,450 $485
1881-82	TAMWORTH Peel	1	1	No	7	A & R Amos	J.O&C.E.Brettell Worcester, England (190)	J.S.Bennett	Stockton Forge Co (155)	16 Nov 1881 20 Feb 1885	9 Jan 1882	£9,550 $420
1881-82	WOOLBROOK MacDonald	1	1	No	7	A & R Amos	J.O&C.E.Brettell Worcester, England (190)	J.S.Bennett	Brick Abutments	20 Feb 1885	2 Aug 1882	£9,550 $420
1883-84	DUBBO Macquarie	1	3	Yes	4	A & R Amos	Cochrane & Co Middlesborough, England (580)	Benjamin Barnes	Cochrane & Co (741)	23 Apr 1884	May 1884	£49,210 $525
1883-84	ALBURY Murray	2	2	Yes	6	A.Frew	Westwood, Baillie (603)	J.S.Bennett	Stockton Forge Co (509)	24 Sep 1884	18 Oct 1884	£32,520 $669 2 tracks
1884-85	NARRANDERA Murrumbidgee	1	2	Yes	4	Halliday & Owen	Westwood, Baillie (396)		Stockton Forge Co (370)	4 May 1885	May 1885	£22,170 $459
1884-85	COMO Georges	1	6	Yes 2x3	4	C & E Miller	Cochrane & Co Middlesborough, England (1101)		Stockton Forge Co (1077)	19 Jan 1886	26 Dec 1885	£66,140 $453
1885-86	RYDE Parramatta	2	6	Yes 2x3	6	Amos Bros	Handyside & Co Derby, England (1508)		Stockton Forge Co (862)	10 Sep 1886	17 Sep 1886	£69,000 $472 2 tracks
1886-87	COWRA Lachlan	1	3	Yes	4	Fishburn & Co	A.Lecoq Halle, Belgium (540)	D & W Robertson	Stockton Forge Co (982)	2 Sep 1887	2 Sep 1887	£52,000 $459



Construction

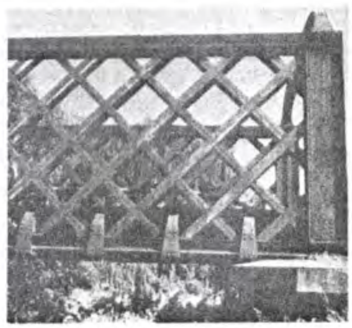


Single track bridge

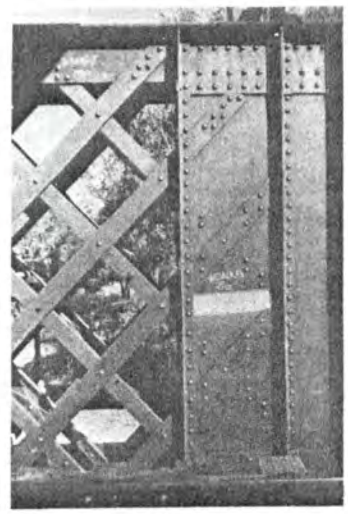


Double track bridge

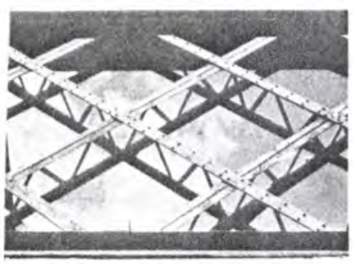
7 triangulations



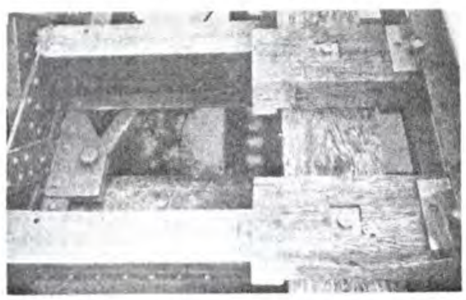
6 triangulations



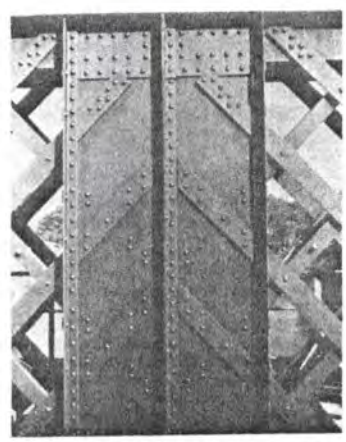
End post



Double-lattice web,4 triangulations



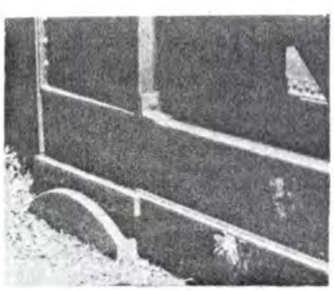
Track on longitudinal timbers



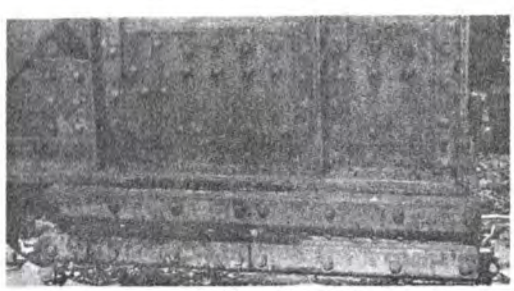
Post at continuous support

Turnbuckles in bracing

Deck system,improved design



Fixed rocker bearing



Roller bearing

Figure 7 Typical details of railway lattice bridges.

Directly related to the number of triangulations is the method of connecting the cross-girders to the main lattice girders, Figure 6. The spacing of the lattice bars is a critical factor (Cargill 1863). Framing the cross-girder into the side of the open trough-shaped bottom chord, Figure 6(a), causes twisting of a section that is structurally inefficient in torsion. The remedy is dealt with later in respect to the twelve railway lattice bridges. Supporting the cross-girders on top of the bottom chord, Figure 6(b), is structurally superior and simpler in detail.

3 RAILWAY LATTICE BRIDGES IN NEW SOUTH WALES

Table II shows a summary of the principal items of information concerning the twelve lattice bridges built for the New South Wales Government Railways between 1870 and 1887. Within the twelve there are only three different designs

1. The first six bridges, built for single lines of railway, have longitudinal timbers supporting the track. The cross-girders are connected to the sides of the bottom chords and the main girders have seven triangulations.
2. Four of the second six bridges were also built for single track and were an improved design. The track is supported by longitudinal steel beams which in turn are supported by cross-girders that rest on top of the bottom chords. The main girders still have double-lattice webs but the triangulations have been reduced to four. These bridges have a more open and lighter appearance.
3. The remaining two bridges, at Albury and Ryde, were built for double track and incorporate all the improved features. The main girders are much deeper and use six triangulations.

All were major bridges of their day, and contemporary newspapers (see references) carried regular reports about them during construction. They were all relatively expensive bridges due mainly to the length of construction time, between one year and 18 months. Their final costs at approximately £75 per linear foot is equivalent to around $15 000 per metre today, based on a labourer's wage of 10/- per day in the 1880's. Modern technology and construction methods enable replacement bridges of similar size to be built for half this amount. Figure 7 shows the technical details of these railway lattice bridges.

All twelve bridges have spans of 48.5m (159 ft) and a common feature of ten of them is the use of continuous spans, mainly in groups of three. The bridges at Albury and Narrandera are two-span continuous and the Wagga bridge has four continuous spans. Only two single span bridges were built, at Tamworth over the Peel River in 1881 and at Woolbrook over the MacDonald River in 1882. The latter is the only bridge not to have cast-iron cylindrical piers. The shallow depth to sound rock enabled solid brick abutments to be used.

When the original sets of working drawings were examined and site inspections made, it became clear that all the bridges incorporated the flexibility of distributing web material, as noted earlier. The sizes of lattice bars at the ends of each spans are much larger than those in the central region of each span, Figure 3, which is consistent with the changes in shear force. In the case of continuous bridges, the distribution of web material matches the different values of shear at each end of the outer spans, and also the shift of the point of zero shear towards the outer supports, figure 3.

Despite the apparent completeness of this dossier there are some questions still to be answered:

- Why use lattice girders? Were other types of bridges considered? Who designed the bridges? Why use 48.5m (159 ft) spans? Why use the same span at all sites?

The authors have not yet found specific statements about these matters, but the following answers are quite plausible.

1. Since lattice girders were the dominant type of bridge in Britain and its colonies, then its choice could be classed as routine, probably inevitable. As late as 1890, the Commissioner and Engineer-in-Chief for Roads and Bridges, Robert Hickson, considered "lattice girders to be the best type of bridge" (Cowra Bridge Report 1890).
2. There is only a faint possibility that other bridge types were considered, despite the fact that two "American style" Whipple trusses were built in New South Wales during the period under review. A report on these two bridges, the road bridge at Nowra 1878-81 and the rail bridge at Lewisham 1885-86, has been presented elsewhere (Fraser 1981). One span of the Nowra bridge was on display at the 1881 International Exhibition in Sydney. The Judges concluded "unless under peculiar circumstances, the lattice type of bridge is preferable for both railway and road in this Colony", (Main Roads, 1971).
3. All the working drawings have the stamp of John Fowler, the eminent British consulting engineer, who was Agent for the New South Wales Government. Although some original design work may have been carried out by John Whitton (Engineer-in-Chief, NSWGR) or his staff, it seems most likely that responsibility for design and preparation of drawings rested mainly with John Fowler.
4. The technical references show that a span of 48.5m (159 ft) was within the economic range for lattice girder bridges. Since the initial six railway bridges used longitudinal timbers over 0.91m (3 ft) spans to support the track, then any chosen span had to be divisible by three. For the later bridges, with steel stringers over spans of 1.3m (5'8") and 2.26m (7'5"), the 48.5m span seems irrelevant.
5. The years 1870-1890 were a hectic period of railway expansion and construction in New South Wales. All the bridges were fabricated overseas (Table II). Therefore, it seems likely that the original design for crossing the Hunter River at Aberdeen, 1870-1871, was adopted as a "standard" in order to save design time and maintain delivery and construction schedules.

4 ANALYSIS OF LATTICE GIRDERS

The contemporary technical literature contains a number of methods for the analysis of lattice girders. These methods may be classified in two ways, the use of beam analogy and the use of truss theory. Only one from each class will be dealt with here, Rankine (1856, 1882) and Warren (1894). The lattice girder shown in Figure 8(a) will be used to briefly explain the two methods and their results will be checked using a modern computer-oriented method.

4.1 Beam Analogy

The lattice girder is visualised as a beam with an open rather than a solid web. Elementary statics of beams in bending is then applied to calculate the bending moments, M, and shear forces, S, at sections mid-way between the load joints, Figure 8(b). From

the conditions of internal equilibrium $C_f = T_f = M/D$ and $C_w = T_w = S/(4\sin\theta)$. If a shear force diagram and bending moment diagram are used, the analysis need only occupy one standard calculation sheet.

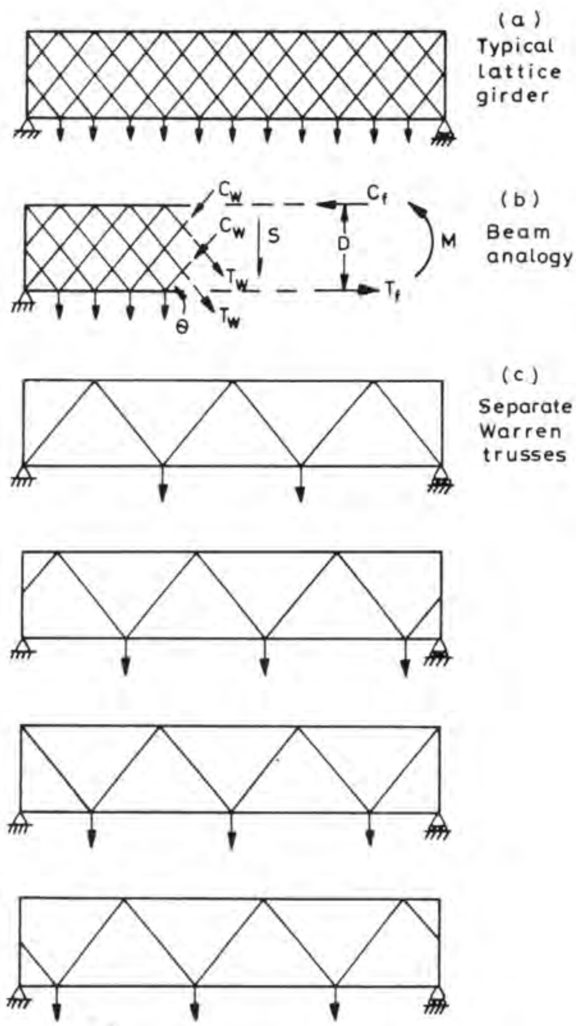


Figure 8 Analysis of lattice girders

4.2 Truss Theory

The lattice girder is visualised as a series of overlapping Warren trusses, equal to the number of triangulations. These trusses are analysed separately, Figure 8(c), and the results added together. The calculations would normally take more sheets than the beam analogy method, however, Prof. Warren does show how the analysis by truss theory can be presented in a compact table.

4.3 Computer Analysis

The previous methods have three sources of error -

1. All lattice bars are assumed to be pin-connected to the chord members, whereas the amount of rivetting suggests a relatively stiff joint which could generate secondary bending in the web members and in the chords.
2. The joints between chord members and posts are also assumed to be pins whereas the substantial rivetting would approximate a rigid joint.
3. The rivetting of the lattice bars at their intersections is ignored, each bar being considered as a separate member from its top to bottom chord joints. The reality of the connections renders the web highly indeterminate and must cause some redistribution of the web forces. Modern computer methods enable all these factors to be taken into account. For reasons of space, none of the details are given here. The results from all three methods are in reasonably good agreement for the member axial forces. However, the secondary bending moments in the chords are significant which could lead to an unsatisfactory level of combined stress.

5 THE RESEARCH

The brevity and ordered nature of this paper is completely opposite the realities of the research effort. Indeed, if the paper and its presentation are taken as a unit measure of effort then the background effort was in the order of one hundred-fold.

Research began in early 1980 at the Archives Office, State Rail Authority of New South Wales (SRA), with an examination of some original drawings, historical notes, photographs (contemporary and recent), Annual Reports 1870-1890, and most important, a copy of the Railway Bridge Inquiry Report 1884-1886.

The setting up of this Inquiry by the New South Wales Government was the result of personal animosity between the Engineer-in-Chief, John Whitton, in charge of railway construction and the Engineer for Existing Lines, George Cowdery, in charge of railway maintenance. Cowdery planned to have repairs and other work carried out on the six earliest iron lattice bridges and he requested plans and data from Whitton. The request was refused on the grounds that the bridges had been soundly constructed and the nature of the repairs and their effect upon the safety of the bridges had been exaggerated. Cowdery appealed to the Minister for Public Works who was presented with conflicting opinions, technical and personal, from both men. In order to resolve the matter, the Minister set up a Select Committee to inquire into the safety of the iron lattice bridges and of certain timber viaducts. The Committee came to some face-saving conclusions for George Cowdery and recommended some minor repairs, such as replacing some loose rivets, plus the exchange of plans and other technical information. However, the technical opinion of John Whitton and the safety of the bridges were vindicated then, and during the next one hundred years of service, by carrying loads well in excess of the original design.

The final report of the Select Committee contained much valuable information about lattice girder bridges, particularly technical, because Professor Warren from Sydney University and Professor Kernot from Melbourne University were members of the Committee. The results of their analyses of the single span and of the continuous span lattice girder bridges are contained in the Appendix and the Special Reports.

Despite this good start to the historical research, only about half the information in Table II was obtained and then mainly about the first six bridges. Most of the remaining information was obtained from a slow, patient search of contemporary newspapers (see references) at the State Library, Sydney, principally the Sydney Morning Herald. The most daunting feature of this work was the general lack of indexes.

The whole process would rival any detective work, with its mounting volume of news items and dates, sometimes confusing the search, but mostly clarifying matters. For example, the bridges at Wagga

Wagga, Dubbo and Albury were completed almost a year after the railway lines were opened for service. The initial river crossings were all carried on temporary timber viaducts.

Enquiries were not confined to Australia. Some relevant information was obtained from sources in England, particularly the library of the Institution of Civil Engineers, London (Chrimes 1980).

Concurrent with a search of old newspapers and archive records was a search of old calculation books and reports dealing with colonial railway bridges. These documents are held by the Way and Works Branch of the SRA, and were made available by the co-author, Ross Best.

Each of the twelve railway lattice bridges was visited, photographed in detail and many measurements taken in order to clarify data shown on the faded and sometimes damaged original drawings.

All this material forms a large dossier of research notes that are presently the subject of a comprehensive report by the authors. The report will be held at the SRA Archives Office.

6 ENGINEERING HERITAGE AND PRESERVATION

The twelve lattice girder bridges in New South Wales represent the first major programme of iron bridge construction in the colony and they were vital components of the rapidly expanding railway network.

The bridges crossed two wide coastal rivers and there were ten crossings of the inland rivers, rivers capable of large and violent floods, and yet all bridges have survived nearly 100 years and more.

Three of the bridges, at Aberdeen, Como and Ryde, no longer carry rail traffic and are destined to be removed, probably as scrap iron. However, although they do not meet modern railway requirements they are suitable for re-use in less demanding situations. For example, the 1882 lattice bridge over the Iron Cove, Sydney, now serves as a road bridge near Forbes and has an appropriate commemorative plaque attached.

All the bridges have served the railway system and the State well through a century of changing and increasing demand. They have significant merit in terms of engineering heritage.

7 CONCLUSION

This paper has presented a case study of the historical research of a group of lattice girder bridges built in the colonial years 1870-1890 in New South Wales.

The investigation was a major project extending for nearly two years. It highlighted two essential characteristics of a successful researcher, patience and persistence. Not all the information about the bridges was in the obvious place and there were consequent periods of frustration as the investigation appeared to founder. However, these were relieved by elation when the relevant information was found.

The paper summarises the results of the research and has indicated the nature and extent of the research effort involved.

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